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THE GORDON RICHARDS MEMORIAL LECTURE 1960
FACTORS INFLUENCING MAXIMUM PERMISSIBLE DOSES OF RADIATIONS*

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Mr. President, Ladies and Gentlemen: You have done me a great honour by asking me to deliver the Gordon Richards Memorial Lecture for 1960. I will do my best on this occasion to present some material to you in a manner befitting the memory of such a great radiologist.

It was my good fortune to have known Dr. Richards as a physician, teacher, and colleague. My first memory of him is as a physician-radiologist, when, as a student at the University of Toronto, I was referred to him for X-ray examinations. He was extremely kind, considerate, and efficient. As a teacher, I remember him as a very formal lecturer but one who was clear and had his material well organized. I used my notes on his lectures to help organize my teaching when I became Instructor in Radiology at the University of California in 1928. My early memory of him as a colleague is that of a very reserved man. As the passage of time made the ten odd years' difference in our ages less of a barrier, I found him to be an understanding friend. Nevertheless, I always looked up to him as my highly respected teacher. The intelligence, skill, and capacity for work that made him a Gold Medalist at college continued with him throughout his life.

The subject of this lecture is *Factors Influencing Maximum Permissible Doses of Radiations.* My intention is to interpret the subject broadly and to include some recent interpretations, explanations, and changes made in 1959 by the International Commission on Radiological Protection,[27] of which I am a member. The plural "doses" must be used because not only are there different maximum permissible doses for the exposure of the total body, of the extremities, and of the separate organs, but also for various groups in the community.

Population Groups

In the days when X-rays and radium were used almost exclusively by physicians, only a few people were exposed to ionizing radiations, but when nuclear reactors were put into operation and radioactive elements were made in great quantities, man started to contaminate air, water, and food, and thus to involve whole populations in the problem of protection. Nevertheless, the benefits of nuclear power and medical radiology are so great that some method must be found for the regulation of exposures so as not to produce too much genetic change.

The International Commission on Radiological Protection found it advantageous to set up categories or groups, for each of which there is a different maximum permissible exposure:

1. Occupational radiation workers
2. Adults who work in the vicinity of a controlled area
3. Adults who enter a controlled area occasionally in the course of their duties but are not radiation workers
4. Members of the public living in the neighborhood of a controlled area
5. The population at large.

A controlled area is one in which the *occupational* exposure of personnel to radiation or radioactive material is under the supervision of a radiation safety officer, for example, your own radiological office where you are the safety officer, or the whole plant at Chalk River with a chief safety officer and many assistants.

For very low doses, it is well established that gene mutations are the greatest hazard. Insofar as whole populations are concerned, the same number of mutations will result whether 100 people each get 100 rems, or 1000 people each get 10 rems, or 10,000 each get

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1 rem. If the exposure of the population at large is strictly limited, then it is possible to permit larger doses to the occupational workers without greatly raising the rate of mutation in the germ plasm of any given whole population.

The occupational groups are those that voluntarily choose to work where conditions are such that they will receive more exposure than the population at large. So long as this group is only a small fraction of the general population, the total genetic hazard is not much increased by the dose the persons in this group receive and, therefore, the maximum permissible level for them is based mainly on the somatic effects for each person.

The other three groups are certain to receive more radiation than the population as a whole because of their proximity to radiation controlled areas. Of these three groups, the last one, namely, the public living in the neighborhood of controlled areas is the most important because it will contain children and pregnant women whose offspring will therefore be irradiated from conception throughout life. For them, a maximum permissible dose (MPD) of 10% of the occupational level is set, *i.e.*, 0.5 rem per year. The first two subgroups have been assigned an MPD equal to 30% of that of occupational workers, 1.5 rems per year.

Development of Idea of Tolerance

Let us now review very briefly how tolerance doses were established, a subject covered before this Association by Kerwin in 1951.[12] In 1902, thinking in terms of acute injury to the skin, Rollins[28] stated that a dose corresponding to what is variously calculated now as 10 to 20 r was not harmful. He was thinking in terms of the very soft X-rays available at that time. In 1925, Mutscheller[22] established a "tolerance dose" on the basis of surveying a limited number of typical good installations where the doctors and technicians showed no signs of radiation effects on the skin, blood, or general health. The average of these turned out to be approximately 0.2 r per day as calculated from fractions of the erythema dose.

Others, such as Sievert,[36] Barclay and Cox,[1] and Failla,[7] also took measurements of the "intensity" to which some few people had been exposed for a few years without known harmful effects, and from their results calculated a tolerable dose. In 1934 the International X-Ray and Radium Protection Commission[11] took account of all known facts and set the "tolerance dose" at 0.2 r per day. In 1936 the Advisory Committee on X-Ray and Radium Protection of the United States,[42] in National Bureau of Standards Handbook 20, lowered its tolerance figure to 0.1 r per day, apparently because in the United States it was customary to measure the exposure in free air, while on the continent the measurements were made on the skin (with backscatter). Another factor was that the more penetrating rays, which were becoming commonly used, delivered a larger dose to the bone marrow in proportion to the exposure measured in air than did the softer rays. It should be noted that all the above figures were based on observation of personnel for only a few years. The changes that were expected were stated in early protection literature as (a) injuries to the superficial tissues and (b) changes in the blood and derangement of internal organs, particularly the generative organs.

Threshold Versus Linear Effects

The radiologists and physicists who tried to establish tolerance doses in the 1920's and 1930's either used the erythema dose or were well acquainted with it. It was by far the most used "biological" measure before the roentgen was established. Two characteristics of the production of a skin erythema are of special interest: (1) It is a threshold type of reaction. (2) It is dose-rate dependent.

Because there was a threshold dose below which no erythema was produced, it was natural to think that there must be a "tolerance dose" for other biological effects produced by X-rays, below which no effect would be produced. Because there was a clearly demonstrated "recovery factor" when the dose to the skin was fractionated, it was natural to think that a daily tolerable dose could be repeated regardless of the total dose received in a lifetime. After Muller[20] demonstrated the genetic effect of X-rays, evidence was gradually accumulated showing that insofar as gene mutations were concerned the effects were totally additive — no matter what the dose rate or fractionation within the time limits of the experimental material.

If all effects are linear with size of dose from zero upward — in other words, if one unit of exposure produces a unit of effect regardless of the time during which the exposure is received — then there is no tolerable dose and the setting of a maximum permissible dose is a matter of judgment as to how much risk should be acceptable. Taylor calls this the "risk philosophy".[43]

Since the advent of nuclear reactors in 1942, much more attention has been directed to the study of radiation effects. Three general effects have important bearings on the problem of permissible doses. These will be reviewed to see what they contribute toward solving the problem of a tolerable dose versus an acceptable risk.

General Radiation Effects Influencing Permissible Dose

1. *Life Shortening*

Experiments with animals, such as those of Lorenz with mice,[16] have proved beyond a shadow of doubt that daily, chronic, low-level exposures cause shortening of the average lifespan. The experimental literature on the shortening of life by chronic exposure to radiation and its bearing on the maximum permissible dose for man has been reviewed by Mole.[19] Different mathematical analyses attempted to show that each roentgen received shortens life by a given number of days. However, Lorenz's experiments[16] with mice and guinea pigs receiving less than 1 rem per week and those of Carlson[4] with rats receiving 0.8 r per day showed that these animals lived longer than their controls. It is hard to correlate these findings with a non-threshold theory. Another difficulty is to decide what can be inferred from the effects of whole-body, uniformly distributed radiation in small animals when one is estimating the effects of partial-body, very irregularly distributed radiation in man.

Studies of the average length of life of radiologists have been made in the United States and in Great Britain. The study of American radiologists by Seltser and Sartwell, who corrected for the age composition,[35] shows no decreased lifespan. The British study by Court-Brown and Doll[5] concluded, in part, "A summary of the mortality of British radiologists during the period 1897 to 1956 reveals no evidence of any non-specific reduction in their life expectancy, such as could be provided by an increase in the age-specific mortality rates for all causes of death". In this connection, it should be remembered that the first protection rules were published in Britain in 1921, and before that time many radiologists must have received fairly large doses as judged by today's standards.

I do not know what the statisticians and theoreticians will do with the low-level total-body exposures of animals that cause life lengthening, or with the fact of no shortening of the life of radiologists, but from a practical point of view there is a threshold effect even if we do not know the threshold dose. It seems very probable that when the maximum permissible dose was 0.1 r per day, equalling 30 r per year, it was below the threshold for life shortening.

2. *Leukemia Induction*

The fact that ionizing radiations can cause leukemia in mammals — including man — is now well established; it is known, as well, that the incidence increases with increase of acute dose or of large chronic doses. The problem of threshold or no threshold dose has become one for the statisticians to tackle. I have the impression that, on the whole, those good with the statistical method know too little of the biological variations, and vice versa.

Court-Brown and Doll,[6a] after studying the induction of leukemia in patients irradiated for ankylosing spondylitis, concluded, in part: "The authors suggest the adoption of the working hypothesis that for low doses, the incidence of leukemia bears a simple proportional relationship to the dose of radiation, and that there is no threshold dose for the induction of the disease." Brues[3] thinks that they should not exclude those who got high doses, and that when this is not done he finds that the leukemia incidence departs from a straight line and suggests a very small or no response at low doses. When Court-Brown and Doll[6b] analysed the data concerning 18 leukemic patients who were from the group receiving irradiation to the spinal axis only, they found that they suggested a threshold of 54 rems by one method of analysis and of 130 rems by another. Because of the uncertainties in dealing with so few cases, this threshold might lie anywhere between 0 and 460 rems.

Brues feels that the best we can tell about the data from Hiroshima is that only doses above 100 r are leukemogenic. Lewis[15] made studies of all data he could obtain about leukemia induction by X-rays and calculated the probability of leukemia induction for the individual per rad per year. Brues,[3] however, after reworking the data, made the following statement: "If we repeat his [Lewis's] data on a logarithmic graph, we find a better fit is obtained if we assume that the leukemia hazard follows the square of the dose, or if there is a true threshold, at around 70 r".

Lorenz[16] described certain experiments which I had the privilege to help plan and watch. Mice were subjected to chronic exposures at known levels for 8 hours per day to simulate the conditions of radiation-worker exposure. The LAF_1 mice exposed to 0.11 r and 1.1 r per 8-hour day had essentially the same incidence of leukemia as the controls, while those exposed to higher levels developed more leukemia. For all practical purposes, this demonstrates a threshold effect.

It would seem that so far as leukemia production is concerned, expert opinions can be found on both sides of the question as to whether or not there is a threshold, but, in my opinion, there is.

3. *Genetic Effects*

For many years it has been accepted that for point or gene mutations of *Drosophila* there is a totally additive (linear) relation

between dose and effect. Even here, however, it has never been and probably cannot be shown that this relationship holds for all doses down to those from natural radiation. Russell[33] showed that similar relations hold for irradiation of mouse spermatozoa and that the mutation rate per roentgen was fifteen times higher than in *Drosophila*. More recently, however, Russell[34] has shown that when spermatogonia of mice are irradiated there is a dose-rate effect. This does not prove that there is a threshold effect, but it leaves the possibility open. This work is so important that I shall quote Russell's own summary:

"New data have clearly confirmed the earlier finding that specific locus mutation rates obtained with chronic gamma irradiation of spermatogonia are lower than those obtained with acute X-rays. Since this result is in contrast to classical findings for *Drosophila* spermatozoa, and apparently contradicts one of the basic tenets of radiation genetics, it was important to determine what factors were responsible for it.

"Experiments undertaken for this purpose reveal the following:
(i) the lower mutation frequency is due mainly to difference in dose rate of radiation, rather than quality; (ii) a dose-rate effect is not obtained in experiments with mouse spermatozoa, confirming classical findings for spermatozoa, and indicating that the explanation for intensity dependence in spermatogonia resides in some characteristic of gametogenic stage; and (iii) a dose-rate effect is found not only in spermatogonia but also in oocytes, where cell selection is improbable, indicating that the radiation intensity effect is on the mutation process itself.

"A threshold response for all mutations in spermatogonia and oocytes is not a necessary consequence of the findings. Plausible hypotheses consistent with the present results can lead to other predictions.

"From a practical point of view, the results indicate that the genetic hazards, at least under some radiation conditions, may not be as great as those estimated from the mutation rates obtained with acute irradiation. However, it should not be forgotten that even the lower mutation rates obtained with the present intensity levels are still appreciable."

It should be remembered that mutations involving gross structural changes of chromosomes are known to be dose-rate dependent.[21] There is a certain amount of healing possible, *i.e.*, recovery, if time is allowed between the various processes.

From the above, we can conclude that all genetic effects are not directly dependent on total dose regardless of dose rate and fractionation. Much more information is needed before we can establish the presence or absence of a threshold level. There is still considerable uncertainty as to what dose of radiation is going to produce too heavy a burden of mutations for the human race to stand.

One of the major reasons for repeatedly lowering the maximum permissible dose in recent years was to keep the total population's gonadal dose down to the lowest level consistent with the profitable use of nuclear power and of X- and gamma-rays.

4. *Population Exposure to High Natural Radiation — Kerala*

Gopal-Ayengar,[8] in a preliminary report to the IXth International Congress of Radiology in Munich, July 1959, gave some interesting information bearing on the subject of tolerance. He emphasized that he was giving a preliminary report and that extensive studies will have to be made to establish the facts. A group of the population of Kerala, India, live along the beaches — their homes are built there and most of their activities, both social and economic, are carried out there. The sands of these beaches contain an extremely large quantity of monazite and other radioactive minerals. In most parts of the world, the average natural radiation at sea level is about 100 mr per year, but in Kerala, it is approximately 10 to 15 times this level. In certain of the native huts built with materials from the beach, levels of activity are as high as 4000 mr per year. Since the population is fairly static, the offspring of these people who for many generations have been exposed to a significantly increased amount of natural radiation offer an opportunity to study the effects of life-time exposure.

A comparison of these Kerala inhabitants with another (control) group of Indians very similar in culture, nutritional status, and economic background has not revealed any obvious shortening of lifespan, alteration of the sex ratio, or other obvious genetic defects in the Kerala group. Gopal-Ayengar stated that the people of Kerala are fertile and are apparently leading normal lives.

Note that some of these people get 4 r per year from birth to death, and this would mean 120 r by age 30. The average, however, is closer to 1 r per year, or 30 r by age 30.

In spite of these few rays of hope coming through the dark clouds of prediction of doom by the geneticists, it is my opinion that we should still assume that there is no threshold for genetic effects and therefore the gonadal exposure should be kept very low.

When all of the information at present available was reviewed by the ICRP in 1959,

it concluded that no decision could yet be reached as to whether or not maximum permissible doses for those occupationally exposed can be based on threshold reactions. Certainly the gonadal dose to the population must for the time being be based on a non-threshold theory.

Decisions Reached by ICRP, 1959[27]

During the 1959 meeting of the ICRP in Munich, several topics were discussed and some decisions were reached that will be of interest to you.

1. *Pregnant Women — Women of Reproductive Age*

The question of the employment and exposure of pregnant women was discussed. You will recall that Russell[30,31,32] had shown that doses as low as 25 r delivered to mice embryos *in utero* had caused marked changes, especially when delivered in the early stages of pregnancy. She reported to the Commission that she had not been able to show such changes with doses of 4 r but stated that it would take a large number of animals to prove that there were no changes at such low levels. It is believed that in man the highest degree of radiosensitivity during prenatal life probably occurs from about the 18th through about the 38th days following implantation.[29] If this is so, then many women of childbearing age who might be working in controlled areas could be pregnant and not know it for a part of this period. In the light of this information, the Commission decided that it would add to its 1958 recommendations[26] the following sentences:[27] (1) "It is especially in respect to somatic damage in foetal tissues that pregnant women present a 'special risk problem' in the case of occupational exposure." (2) "Any special recommendations for pregnant women must in practice apply to all women of reproductive age."

Another paragraph of 1958 recommendations was thought to need clarification insofar as it applies to women of reproductive age. It concerns the rate of accumulation of dose and says, in part: "If necessary, the 3 rems (per 13 weeks) may be received as a single dose, but as the scientific knowledge of the biological effects of differing dose rates is scant, single doses of the order of 3 rems should be avoided as far as practicable."[26] The Commission, meeting in 1959, decided to add the phrase, "*especially in the case of women of reproductive age*".[27] There is another paragraph which allows an emergency occupational exposure of 12 rems as a single dose, but it states, "*Women of reproductive age shall not be subjected to such emergency exposure.*"[26]

2. *Exposure of Population at Large*

In the 1958 recommendations of the ICRP,[26] maximum permissible doses were indicated for occupationally exposed individuals and for the individuals in certain special groups. None was even suggested, however, for "individuals in the general population". It was assumed that the maximum permissible genetic dose to the whole population would take care of this. Such a dose, however, is arrived at by averaging over the whole population (and weighting for age). This leaves it possible for one or more individuals to get a high dose, provided the dose to the rest of the population is low. Hence it was felt necessary to make some statement regarding the maximum exposure of individuals in the population. The statement refers to both external and internal exposure and reads as follows:[27] "The maximum total dose limit for *individuals* in the population at large (excluding those occupationally exposed, and the special groups B (a) and B (b)") [adults working in the vicinity of a controlled area, and adults who occasionally enter control areas] "should be that recommended for members of the special group B (c)," [the public living in the neighborhood of controlled areas], *i.e.*, 0.5 rem per year in the gonads, the blood forming organs, and the lenses of the eye.

3. *Working Hours and Length of Vacation*

The International Labor Office, among others, wanted the opinion of the ICRP on the working hours and length of vacation for workers in radiation controlled areas. After considerable discussion, the consensus was given in a single sentence:[27] "The Commission considers that with the present maximum permissible exposure levels no special treatment of radiation workers with respect to working hours and length of vacation is required." In other words, if you are working in radiation controlled areas and staying within the rules, then your health is no more in jeopardy than that of workers in any other occupation.

4. *Exclusion of Medical Exposure from Accumulated Occupational Dose*

In the 1958 recommendations of the ICRP[26] (paragraph 46), the Commission *excluded medical exposure* insofar as calculating total *occupational dose* is concerned: "In any organ or tissue the *total* dose due to occupational exposure shall comprise the dose contributed by external sources during working hours and the dose contributed by internal sources taken into the body during working hours. It shall not include any medical exposure or exposure to natural radiation."

In another place (paragraph 35), the report states, "However, individual doses resulting from medical exposure are excluded from all maximum permissible doses recommended in this report." The art and science of communication are difficult! Many people chose to interpret the above statements as meaning that the exposures of doctors, dentists, and technicians while doing medical work would not be included in occupational exposure! The Commission felt it necessary to explain the situation: "The Commission wishes to emphasize that 'medical exposure' refers to the exposure of *patients* that is necessary for medical purposes and *not* to the exposure of the personnel conducting such procedure."[27]

5. *Rate of Dose Accumulation — the 13-Week Period*

The rate at which a given dose is accumulated is known to be very important by every radiologist as a result of his daily work. We do not need animal experiments to prove to us that there is some recovery from clinical radiation injury. The radiologists and radiation physicists who first described tolerance doses felt that the rate as well as the dose was important. Some went so far as to express tolerance as a dose rate per minute or even per second. The common unit of time in which to describe a dose rate used to be a day. Our Russian colleagues believe that maximum permissible doses should be expressed only as daily doses, for example, one-tenth of a roentgen per day rather than five-tenths in a week of five working days, which in essence says you can receive 0.5 r at any rate at any time during the week.

The ICRP and the National Committee on Radiation Protection in the United States have spent hours reviewing all the known facts. It is clear that an exposure of 600 r of total-body radiation in a very short interval of time is likely to result in the death of any individual so exposed; on the other hand, an exposure of 600 r distributed over 40 years at the rate of 0.05 r per day, six days per weeks, and 50 weeks per year, is likely to result in no detectable effect. Animal experiments conducted by Henshaw[10] showed that 8.6 r per day, six days per week, was less effective in killing mice than 51.6 r per week given in one exposure each week.

The Commission faced the fact that film badges, which are generally used, are useless for measuring daily doses in the permissible range. They are not very satisfactory even for weekly measurements and many industrial (and medical) installations are using them on a quarterly basis. It was agreed that an exposure of 3 r would not produce detectable effects even if given at one time, and this was established as a permissible dose to accumulate in a quarter of a year. If it were so stated, however, it would be possible to be exposed to 3 r the last day of one quarter and again the first day of the next quarter — making 6 r in two days or less. Hence the rule states, during "any 13 consecutive weeks" (i.e., in *no* 13 consecutive weeks shall the dose exceed 3 rems).[26]

It is difficult to check records both backward for 13 weeks and forward for the same period, and in many places the rate of receiving exposures is fixed by the barriers, etc. For this reason, the Commission has eased the rule of any 13 consecutive weeks to say, "A calendar 13-week period may be used instead of a period of 13 consecutive weeks *if there is no reason to suppose that doses are being accumulated at grossly irregular rates.*"[27]

The Radiologist's Responsibility

The ICRP has given recommendations or suggestions with regard to maximum permissible doses for exposures to ionizing radiation in (almost) all circumstances except medical radiology. In this field, it is their opinion that the doctor should balance the good against any possible harm. The Commission states, in part: "The contributions to the doses in various organs and the part played in the overall effects on the individual are practically impossible to evaluate at the present time. The Commission recognizes especially the importance of the *gonad* doses resulting from medical exposure and the attendant genetic hazard to the population. Accordingly it recommends that the medical profession exercise great care in the use of ionizing radiation in order that the gonad dose received by individuals before the end of their reproductive periods be kept at the minimum value consistent with medical requirements."[26]

1. *Benefits Versus Risks*

These rulings of the ICRP put decisions regarding the medical use of ionizing radiation squarely on the shoulders of the medical profession. To make intelligent decisions, we must know the hazards as well as the advantages. In medical radiology, as in occupational exposure, we have entered the era when we must balance the risks against the advantages — the risk philosophy again.

The British Ministry of Health, Department of Health for Scotland, set up a committee to study "radiological hazards to patients", commonly called the Adrian Committee. Its first interim report,[18] concerned with the benefits and hazards of mass miniature fluororoentgenography of the chest, provides the data for the next two paragraphs.

In 1957, about 4,771,000 radiographs were made in Britain. On the credit side of the ledger, the Committee listed the detection of about 18,000 cases of pulmonary tuberculosis that needed supervision, nearly 12,000 cardiac abnormalities, 9400 cases of pneumoconiosis, and nearly 2400 cases of lung cancer. Against this is a mean ovarian dose per female of 0.12 mr, a mean testicular dose per male of 0.7 mr, and a mean bone marrow dose of 74 mr. The Committee, while not admitting that such low doses cause leukemia, used the upper figures of the U.N. Scientific Committee on the Effects of Atomic Radiation to calculate that the maximum number of cases could be 20 per year, added to the present incidence of 2500. They add, "but may produce none at all", and with that I heartily agree. Taking the same basis for calculation, they show that an individual who has 10 mass miniature radiographic examinations over a series of years would have his chance of developing leukemia in any year increased — if at all — from 50 in a million to, at most, 51. They state, "We are satisfied that the somatic risk of doses at these levels is on any interpretation far outweighed by the benefits of mass miniature radiography."

The risk of gonadal damage is harder to evaluate, but concerning the gonadal risk from 0.12 mr and 0.7 mr the Adrian Committee said, "From natural sources the annual dose received by an individual would increase by about 20 mr on going from a stone house in a limestone district to a granite house in a granite area (local gamma-ray increment), or going from sea level to live at an altitude of 5,500 feet (cosmic ray increment)."

2. *Sensitivity of Embryo and Foetus*

The abnormal sensitivity of the mouse embryo to radiation at various stages of development is well established.[31] Stewart reported in a preliminary way in 1956[39] that she and her co-workers thought they had found a connection between irradiation of the embryo, or foetus *in utero*, and the incidence of leukemia and other malignancies in the first ten years of life. Paterson[24] and others[25] have corroborated her findings, but others have not. A study by Manning and Carroll[17] using leukemic children in the Children's Cancer Research Foundation, Boston, seemed to show that children of mothers with a positive history of hay fever, asthma, or hives who incidentally had been on antihistaminic drugs, showed a higher incidence of leukemia and lymphoma than the controls.

Stewart and co-workers in a second, more elaborate report,[40] while still affirming that "there appears to be no doubt that there is a causal relationship between pre-natal (and early post-natal) exposure to X-rays and the subsequent development of malignant disease . . .", nevertheless concludes, "Our final conclusions are that foetal irradiation does not account for the recent increase in childhood malignancies, but the finding of a case excess for this event does underline the need to use minimum doses for essential medical X-ray examinations and treatments." In another publication, Stewart[38] summarized her work and concluded, "There appear to be several factors which increase the frequency of malignant diseases in childhood, though nothing so far discovered indicates the root cause of these diseases. Thus, direct irradiation *in utero* undoubtedly increases the chance of dying in this way, but so also may pulmonary infections, threatened abortions, or excess maternal age at the time of birth. What the survey has shown is that there are among new-born babies, some who are already predisposed to the development of malignant disease and that one of the predisposing factors is direct exposure to X-rays before birth."

Radiological examinations during the first four months of pregnancy bring in the problem of the peculiar sensitivity of embryonic tissues at the time of differentiation of specific tissues and organs. Hammer-Jacobsen[9] has reviewed this subject as it affects patients and believes that in some cases therapeutic abortion is justified after abdominal or pelvic irradiation of a pregnant woman. His preliminary suggestions are: "Foetal doses below about 1 r do not indicate induction of abortion. Foetal doses between about 1 r and about 10 r indicate therapeutic abortion only in the presence of additional indications. Foetal doses above about 10 r presumably always indicate abortion." He believes that X-ray examinations of the abdomen should not be performed during the first four months of pregnancy and suggests the following routine precaution: "In fertile women X-ray examination of the abdomen should be carried out only during the first ten days after a regular menstrual period of normal intensity and duration." I believe that some such rule will become routine in radiology departments even though many physicians mildy ridicule it today.

Sonnenblick and Berman,[37] using apparatus designed by Braestrup, made direct measurements in the posterior vaginal fornices of ten women during pelvimetric examination consisting of four films: one lateral, one pelvic inlet, one pelvic outlet, and one for uterine soft tissue. The measured doses were distributed between a minimum of 2.1 r and 4.4 r. A repeated examination of this type could result in a total of 8.8 r. This would be in the danger zone quoted above.

3. *Genetic Dose from Diagnostic Radiology*

Before concluding this lecture, I would like to dwell briefly on the question of how large a gonadal dose the population as a whole is receiving from diagnostic X-ray procedures. At some level of total dosage from all sources this will become critical to the human race. The ICRP made no definite recommendations in regard to a maximum permissible dose to the population as a whole from medical X-rays but, recognizing its importance, nevertheless requested that it be kept as low as possible.[26] Estimates of the genetic dose to the populations of various countries have been made. In the United States, as a result of the Laughlin and Pullman report,[13,14] the most commonly used figure for the 30-year effective gonadal dose per person for both X-ray and diagnostic examinations and radiation therapy is 4.5 rems. This is much higher than for most countries and needed study. Norwood[23] and Brown[2] have used more accurate statistics, Norwood for a small city, and Brown for 100,000 people in a complete medical care program with no restriction on the use of X-ray procedures, in Oakland, California. Norwood found the weighted gonadal exposure from diagnostic roentgen irradiation to be 1.3 r, and Brown found an estimated gonadal dose per person for the first 30 years of life to be 1.2 r.

These figures are much below that in the Laughlin and Pullman report.[13] One of the main reasons for the discrepancy is probably the true age distribution of the patients having the X-ray examinations. Brown's study of the gonadal dose in milliroentgens for different age groups[2] revealed a total for the first 30 years of 1150 mr and for 31 to 80 years, 9750 mr per individual. By a correlation of the frequency of selected examinations against the age of the individuals, he showed that the examinations affecting the gonads are more common after age 30 than before. Norwood[23] calculated that the 6% of examinations that directly irradiate the gonads account for 78% of the gonadal dose. He estimated that the gonadal dose could be cut in half by careful attention to protection of the gonads whenever feasible.

The average gonadal dose associated with a conventional postero-anterior chest film of a female is about 0.2 mr[44] whereas the difference between living in a wooden house and a brick house in Sweden is 55 mr per year.[41] One would have to have about 275 chest films per year to equal the difference, but no one questions the radiation hazard of moving from one house to another. On the other hand, one antero-posterior film of the pelvis and hips of a female gives a dose to the gonads of 150 mr,[44] which equals the increased dose between the two houses for three years; a similar examination of the pelvis of a male gives 450 mr, which equals the increased dose between the two houses for eight years.

Conclusions

The problem of establishing the doses to which various groups of the population can be exposed without injury to themselves or deterioration of future generations has become more difficult rather than more simple as more information has become available.

Until it can be proved that there is a threshold for somatic effects, we cannot set maximum permissible doses that are absolutely safe.

The theory of total additivity of all exposures to ionizing radiation so far as genetic effects are concerned is no longer entirely tenable for man, but until more is known all gonadal exposures must be kept to a minimum.

The sensitivity of the embryo and foetus with regard to production of malformations and early childhood malignancies make women in the reproductive age a special hazard problem as occupational workers.

A balance sheet of the good to be accomplished against the risks to be run shows heavy weighting in favor of the good in the instance of survey photoroentgenograms of the chest.

The total medical radiation hazard has been overestimated, but because there are hazards, it is incumbent on radiologists to take all known precautions to keep the exposure of the gonads to the lowest possible level consistent with the medical needs of the patient.

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AN ASSESSMENT OF THE METHODS FOR DETERMINATION OF THE POSITION OF THE PINEAL GLAND IN LATERAL SKULL ROENTGENOGRAMS

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A calcified pineal shadow is more often visible in lateral than in antero-posterior skull roentgenograms. A critical criterion for the displacement of the pineal gland as seen in the lateral projection is highly desirable for the diagnosis of intracranial space-occupying lesions.

With a view to establishing this criterion, the three classical methods of assessing the normal position of the pineal gland were compared in one hundred and fifty-five lateral skull roentgenograms. All of the patients had had encephalograms, sixty-seven without and eighty-eight with evidence of a space occupying lesion.

Review of Literature

A graphic method for measuring the position of the pineal gland in the lateral projection was first determined in 1927 by Vastine and Kinney[1] (Figure 1). These authors constructed graphs showing the normal range of position in both coronal and transverse planes. A pineal gland situated outside the normal zones was considered displaced accordingly.

In 1930, Dyke[2] used the Vastine and Kinney method in a series of two thousand skulls. He found that in approximately 14% of normal cases the pineal glands fell outside the accepted zones. There was a tendency for the glands to lie anteriorly, therefore in 1936, he advised moving the zone four millimetres forward. His modified charts are shown (Figure 2).

In 1937 and 1938 Fray described two methods for localising the pineal gland in the lateral projection: the proportional and the cranioangle.

The proportional method[3] was arrived at by Fray from the following facts:

(1) The distance from the inner table of the frontal bone to the pineal gland was 55 to 60% of the antero-posterior diameter of the skull.
(2) The distance from the inner table of the vault of the skull to the pineal gland was 51 to 57% of the vertical diameter of the normal skull.

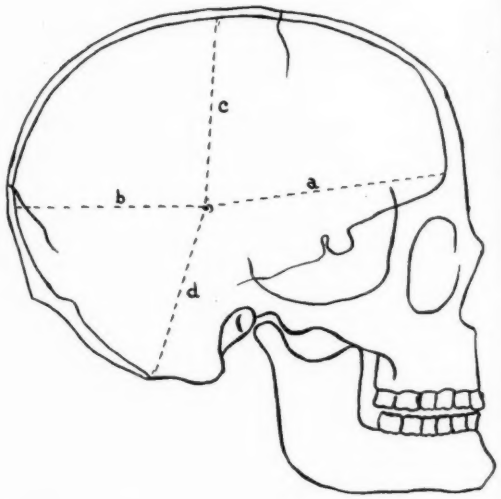


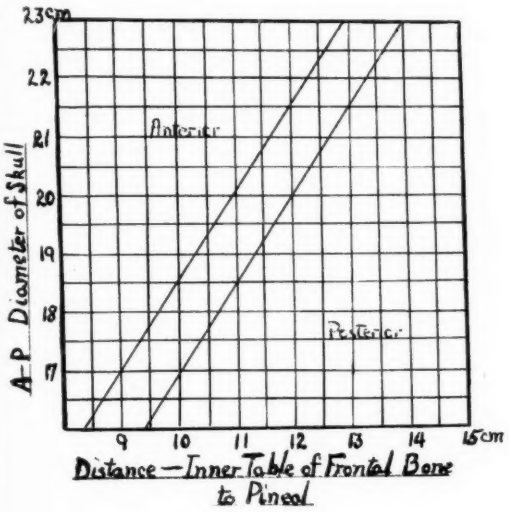
Figure 1 — Measurements used by Vastine and Kinney for determining the position of the pineal gland by the graphic method.
(a) greatest distance from the frontal bone to the pineal.
(b) greatest distance from the pineal to the occipital bone above the torcula.
(c) greatest distance from the vertex of the skull to the pineal.
(d) greatest distance from the pineal to the opisthion.

These findings were transferred to an elastic band. With uniform expansion of the elastic, the normal zone would remain in a normal position relative to the diameter of the skull. This had the added feature that in larger skulls an allowance was made for a proportionately greater range in the normal position of the gland (Figure 3).

Fray's cranioangle method[4] consisted of applying a transparent card to lateral skull roentgenograms. Upon the card were ruled two angles, one of eight degrees and the other of eleven degrees. The vertex of the eleven degree angle was placed at the tuberculum sellae with the base line passing through the lambda. Normal pineal glands fell within the angle above the base line, thus establishing a

*Presented at the Annual Meeting, The Canadian Association of Radiologists, January 27, 1960, Toronto, Canada.

normal position in the transverse plane of the skull. The vertex of the eight degree angle was placed at the opisthion, the base line passing through the bregma. Pineal glands in the normal position in the coronal plane fell within this eight degree angle posterior to the base line (Figure 4).



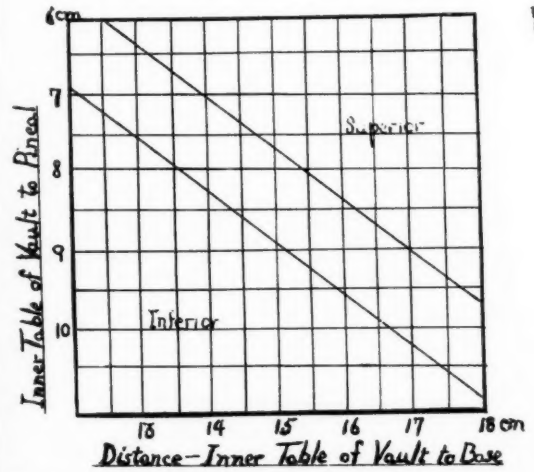


Figure 2 — Line drawings of the actual graphs drawn up by Dyke demonstrating normal zones in the coronal and transverse planes of the skull.

In his assessment of one hundred and four normal skulls, Fray compared the Vastine and Kinney method with the proportional and the cranioangle methods. He found that the Vastine and Kinney method placed the pineal gland in the normal zone in 83% of cases, the proportional method in 92.3% of cases and the cranioangle method in 88% of cases.

Method of Investigation

As previously mentioned the methods used were the Dyke modification of the Vastine and Kinney (graphic) method, Fray's proportional and Fray's cranioangle methods. One hundred and fifty-five cases were tested. All had had encephalograms and these were used as a criterion to detect the presence of intracranial disease. Sixty-seven cases were found in which no evidence of a space occupying lesion could be detected. Of these, thirty-nine revealed no evidence of disease whatsoever and twenty-eight showed ventricular enlargement (probably indicating some degree of cerebral atrophy). In four of the sixty-seven cases the sutures were not well seen and therefore the pineal position could not be measured by the cranioangle method. Table I is an analysis of the results obtained in these sixty-seven cases.

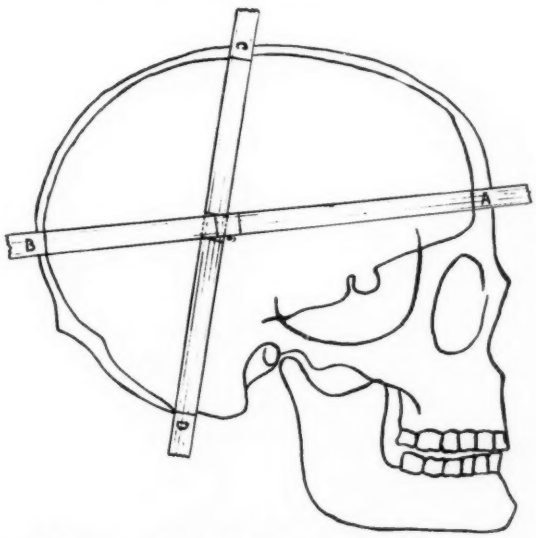


Figure 3 — Line drawings of skull showing proper application of elastic bands according to Fray's porportional method. See text.

According to these results, the cranioangle method is the most accurate. Only 7.9% of normal skulls showed false positive findings whereas the graphic method showed 18% and the proportional 13.5%.

The remaining eighty-eight cases had space-occupying lesions. Table II records the pineal displacement as it occurred in each case according to the three methods used. The cranioangle method could not be used in eleven of the eighty-eight cases because of ill-defined land marks.

In some of these cases, the shift was in a direction other than one would expect from the location of a space-occupying lesion (i.e.,

a frontal space occupying lesion apparently displacing the pineal gland anteriorly). Although this was not a definite indication of an inaccurate result one felt that methods producing such unexpected findings were less reliable. The percentage of these questionable pineal gland shifts found in each group is tabulated in Table III.

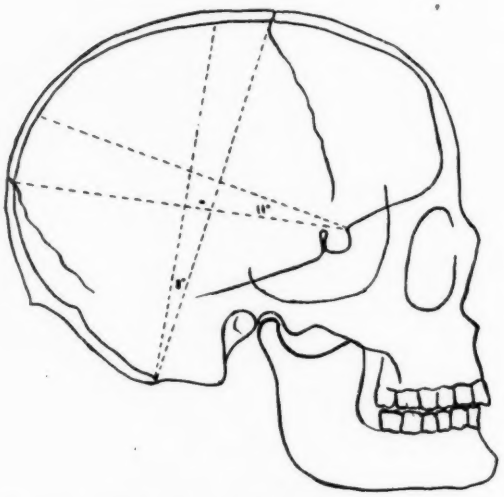


Figure 4 — Triangles applied as in the cranioangle method of Fray. It is important that the baseline be properly applied to the bony landmarks and that the other side of the triangle (the hypotenuse) lie above the baseline of the 11° angle and posterior to the baseline of the 8° angle.

Observations and Discussion

The graphic method, though indicating the greatest number of pineal gland shifts in the presence of tumor, proved itself considerably less accurate when applied to the group which contained no space-occupying lesions. It gave more false positive shifts and more shifts in a direction other than anticipated in view of the position of the tumor. The cranioangle method while proving much more accurate with the normal group showed only 1.6% fewer pineal shifts than the graphic method in the tumor cases. The proportional method was better than the graphic method mainly because it showed fewer false positive displacements (Tables I and II). One significant observation was the absence of an inferior displacement (depression) of the pineal gland in the sixty-seven cases without evidence of space-occupying lesions. This was so, with any of the three methods of assessment used (Table I). Fray[4] recorded depression of the pineal gland four times in his series of 104 normal cases, using the proportional method, but only once using the cranioangle method. Practical experience has shown that an inferior position of the pineal gland is highly suggestive of the presence of a space occupying lesion.

TABLE I

CASES WITH NO EVIDENCE OF S.O.L.
PINEAL LOCATION

	GRAPHIC	PROPORTIONAL	CRANIOANGLE
NORMAL	55	58	58
DISPLACED	7 sup. 1 ant. 4 post.	4 sup. 2 ant. 3 post.	2 sup. 3 post.
TOTAL NO. OF CASES MEASURED	67	67	63
% OF CASES WITH DISPLACEMENT	18	13.5	7.9

Table I — False positive findings as recorded by each method of localization in 67 cases without evidence of a space-occupying lesion.

TABLE II

CASES WITH EVIDENCE OF S.O.L.
PINEAL LOCATION

	GRAPHIC	PROPORTIONAL	CRANIOANGLE
NO. OF CASES	88	88	77
PINEAL SHIFT PRESENT	30	27	25
% WITH PINEAL SHIFT	34.1	30.7	32.5

Table II — Percentage of pineal displacements as recorded by each method of localization in 88 cases with evidence of a space-occupying lesion.

TABLE III

CASES WITH EVIDENCE OF S.O.L.

SHIFTS IN UNEXPECTED DIRECTIONS

	GRAPHIC	PROPORTIONAL	CRANIOANGLE
% OF UNEXPECTED SHIFTS	16.6	11.2	12

Table III — Percentage of shifts in an unexpected direction as recorded by each method of localization in 88 cases of space-occupying lesions.

Thus the investigation was extended, and readily available skulls of unusual contours were selected for special study by the cranioangle method. This method was chosen, because thus far, it had proven the most accurate of the three. Skulls of two types of contour were studied, (a) those having a deep

recess in the occipital bone, immediately above the torcula and (b) those having a high vault with a short wide base (hypsicephaly). In those presenting a deep occipital recess the pineal was not depressed when measured by the cranioangle method.

Skulls hypsicephalic in outline, did however, present an insoluble problem. Two such skulls were studied in detail (Figure 5). In one skull, the coronal suture was fused, but the lambdoid suture patent. It was thus a form of craniostenosis. The second skull had all sutures patent, but was hypsicephalic in outline. The pineal gland was situated superiorly in the skull with craniostenosis, inferiorly in the second skull with the patent sutures.

In these two skulls, the following relationships were analysed and compared:

(1) The ratio between the length of the occipital bone from the opisthion to the lambda and the length of the remainder of the vault of the skull (lambda to nasion).

(2) The ratio between the length of occipital bone from the opisthion to the lambda and the length of the parietal bone.

(3) The angle subtended by Chamberlain's[3] line and a line drawn from the posterior margin of the hard palate to the lambda.

None yielded a satisfactory solution as to why the pineal in one skull was inferior in position, in the other superior.

Summary and Conclusions

A comparison has been made between three accepted methods of assessing the position of the pineal gland from lateral films of the skull — the graphic method of Vastine and Kinney, the proportional method of Fray, and Fray's cranioangle method, using the plain films of the skull of 155 patients who had pneumoencephalograms done.

Approximately 33% of space-occupying lesions will produce a displacement of the pineal gland when any of the three methods are applied (Table II). None of the three methods is entirely satisfactory, but the cranioangle method would seem to be the most accurate method for the following reasons:

1. It gives fewer false positive readings in normal skulls.
2. It gives almost as many positive readings in cases of intracranial tumors. This slight disadvantage is more than compensated for by the reduced number of false positive readings in normal cases.
3. It gives no more unexpected displacements than the other methods.

The one disadvantage of the cranioangle method is that in about 10% of cases, the bony landmarks are not clearly demonstrated and therefore, it cannot be used.

Skulls with high vaults (hypsicephalic) cannot be reliably assessed by this method. The contribution of the occipital bone to the vault of the skull is the determining factor in the measured position of the pineal gland in these cases. No relationship, which would allow one to predict a false displacement was discovered.

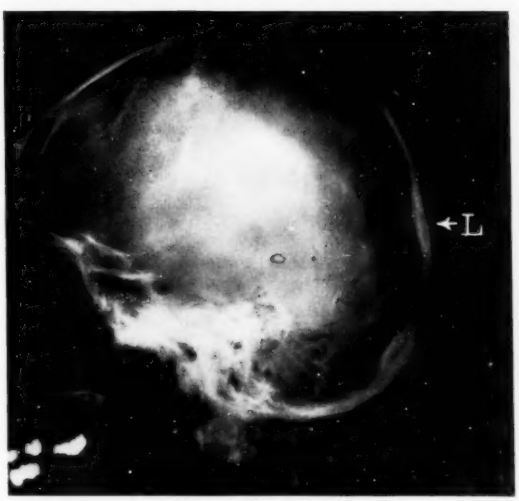


Figure 5 — (a) Hypsicephalic Skull (craniostenosis). Pineal measured superiorly by cranioangle method. Compare position of lambda (L) and relative contribution of occipital bone to vault of skull. (Pineal circled in black).

(b) Hypsicephalic Skull. Pineal measured inferiorly by cranioangle method. Note height of lambda (L) and hence contribution of occipital bone to vault of skull. (Pineal circled in black).

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THE CANADIAN ASSOCIATION OF RADIOLOGISTS

SCIENTIFIC PAPERS — ANNUAL MEETING JANUARY 1961

Radiologists interested in diagnosis and therapy are invited to contribute scientific papers for the Scientific Program of the Annual Meeting of this Association to be held in Saint John, N.B., January 22nd - 25th, 1961. This is the last meeting which will be held in Saint John for several years and every effort is being made to make it strong scientifically, and enjoyable. Suggested titles and abstracts are to be sent to: Dr. J. S. Dunbar, Chairman, Central Scientific Program Committee, The Canadian Association of Radiologists, 1555 Summerhill Avenue, Montreal 25, Quebec.

EDITORIAL COMMENT

The World Health Organization and the International Atomic Energy Agency jointly organized a study group on the use of radio-isotope teletherapy and supervoltage radiation in Vienna last August, and twelve countries were represented. This group, under the Chairmanship of Professor Windeyer of Great Britain, produced a report which is published in the British Journal of Radiology, February 1960.

The main purpose in undertaking this study was to determine the need, especially in countries in which radiation therapy is not well developed, for special training of personnel and for the most suitable types of supervoltage apparatus.

The group agreed that supervoltage equipment is essential in all large radiotherapy centres and it is also most gratifying to observe that the superficial type of fallacious reasoning in dealing with supervoltage therapy as a separate entity is avoided. It is recognized in the report that supervoltage therapy is an integral part of radiation therapy as a whole and that the recommended training programme is one of radiation therapy in its broad aspects, and that all of the broad principles of supervoltage therapy are similar to those governing orthovoltage therapy. The report also recommends certain standards for the training of radiotherapists, physicists, and technicians.

This report should prove of value to those responsible for the implementation of radiation therapy training programmes for medically undeveloped countries.

T. A. Watson, M.B., Ch.B.,

A COMPARISON OF THEORETICAL AND EXPERIMENTAL SPECTRAL DISTRIBUTIONS OF SCATTERED X-RAYS

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It has long been recognized that a substantial part of the absorbed dose from a beam of X-rays is due to radiation which has undergone scattering in the surrounding tissue. If one wishes to express the quality or "effective wave length" of the radiation at some point, a knowledge of the spectrum of both primary and scattered components is required. With the development of the scintillation spectrometer it has been possible to make measurements of such spectral distributions.[2,3,4,5,6,7,10] However there are such wide variations in the irradiation parameters (kilovoltage, focal-skin distance, field area, and depth) that it would be impracticable to try to cover every possible combination of conditions. It would be of considerable value to be able to obtain even approximate spectral data by a theoretical method. Unfortunately no satisfactory method of calculating primary X-ray spectra has yet been found, this problem being complicated by the presence of both continuous and discrete (characteristic) components in the radiation. However, the recent calculations of Bruce[1] make it possible to calculate the scattered spectrum for any of a wide range of depths, areas and focal-skin distances once the spectrum of the incident primary radiation is known. This paper describes a comparison between scattered spectra calculated from Bruce's data and those obtained experimentally.

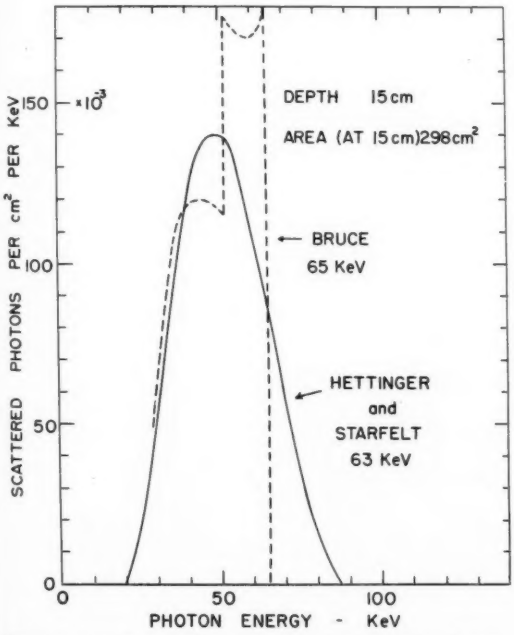

Figure 1 — Comparison of theoretical (dotted) and experimental (solid) scattered spectra generated in water by 65 Kv monochromatic radiation and 63 Kv nearly-monochromatic radiation respectively. The ordinates of both graphs are normalized to a primary number flux of one photon per cm² at a depth of 15 cm.

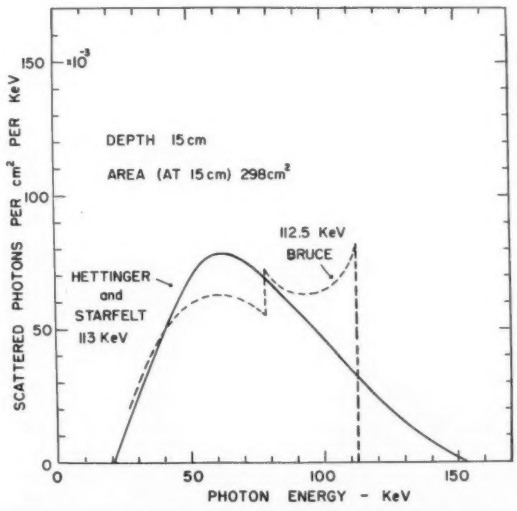

Figure 2 — Comparison of the theoretical scattered spectrum with the measured spectrum for primary energies of 112.5 Kv and 113 Kv respectively. Normalized as in Fig. 1.

Hettinger and Starfelt[6] have recently carried out absolute measurements of the scattered spectra in water irradiated with nearly-monochromatic X-rays with effective energies of 63, 113 and 184 Kv. The number flux spectra integrated over all angles are shown as solid curves in Figs. 1, 2 and 3. The spectra taken from Bruce's tables for monochromatic radiation of 65, 112.5 and 187.5 Kv are shown as dotted curves in these graphs. Both sets of curves are normalized to a primary number flux of one photon per cm²

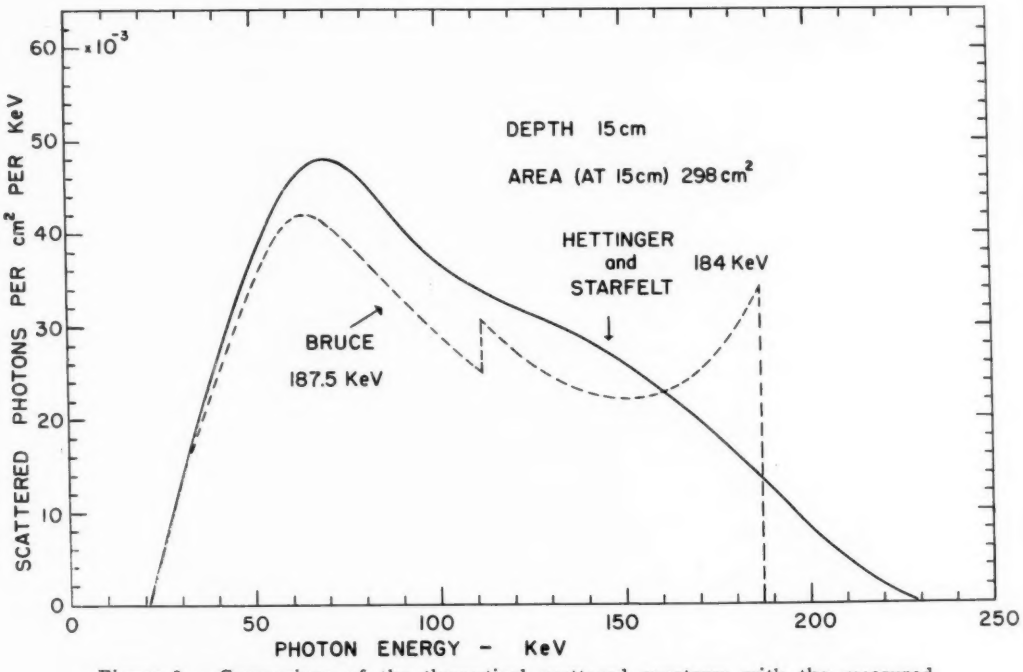

Figure 3. — Comparison of the theoretical scattered spectrum with the measured spectrum for primary energies of 187.5 Kv and 184 Kv respectively. Normalized as in Fig. 1.

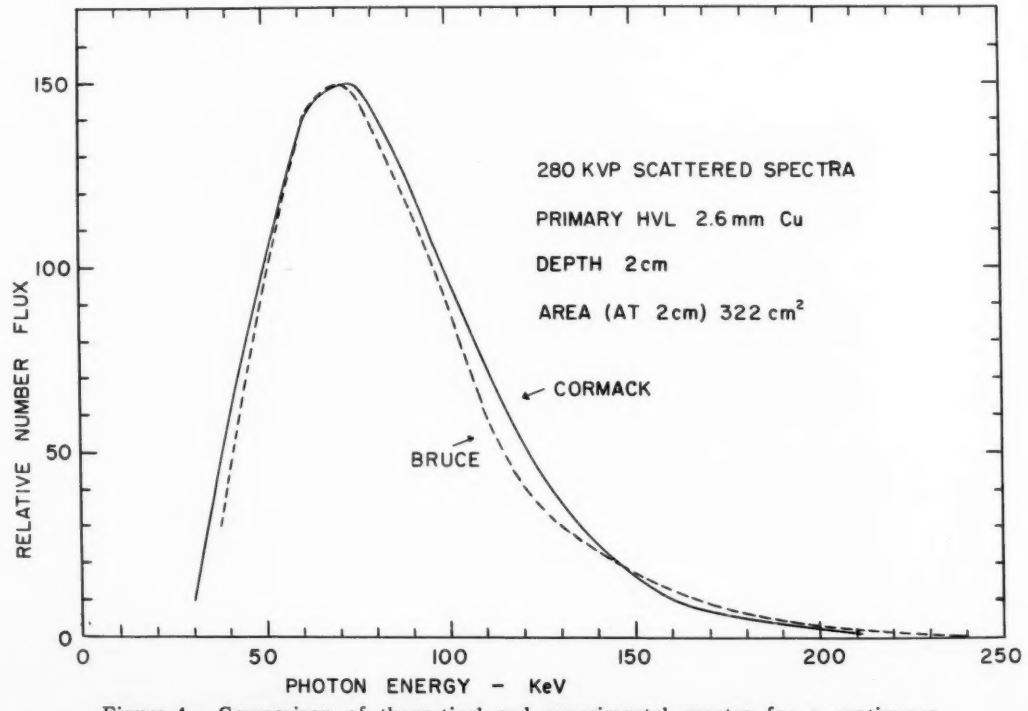

Figure 4 — Comparison of theoretical and experimental spectra for a continuous primary spectrum having a half value layer of 2.6 mm of copper. Depth 2 cm. Curves have been normalized to the same maximum height.

at the depth of 15 cm, and hence may be compared with respect to magnitude as well as shape. Bruce presents his data in terms of the primary flux incident on the surface and hence his values have been multiplied by attenuation factors $e_{\mu d}$ taken from Hettinger and Starfelt. The data of Hettinger and Starfelt were measured with a beam 200 cm² in area at the surface. Since a focal-skin distance of 67.5 cm was used the beam area at a depth of 15 cm would be 298 cm². The latter area was used in interpolating between the areas used by Bruce. Although Bruce's data were obtained for parallel beams, Bruce and others[1,8,9] have shown that they may be applied to diverging beams also provided the spectra are expressed in terms of the beam area and primary intensity at the depth in question. A comparison between the curves in each of Figs. 1, 2 and 3 shows rather good agreement in both magnitude and shape between the theoretical and experimental curves. Since the primary radiation used by Hettinger and Starfelt is not monochromatic one would not expect to observe the discontinuities in the scattered spectra which are predicted by theory.

By interpolation of his data for monochromatic photon beams with photon energies of 50, 100, 200 and 500 Kv Bruce has prepared tables which may be used for calculating the scattered spectra generated by continuous distributions of primary radiation. The use of one of these tables consists essentially of multiplying the primary number spectrum, expressed as a one-column matrix by the matrix composed of the values in the table. Such calculations give the scattered spectra integrated over all angles.

The spectral distribution of both primary and scattered X-rays from a 280 KVP machine have been measured in this laboratory.[3] Using our primary spectral data and Bruce's tables we have calculated the scattered spectra under a number of conditions. Values taken from Bruce's tables were cross-plotted against field area and tables were constructed corresponding to the experimental field sizes at each depth. Since the ordinates of the measured spectra were not determined absolutely no comparison of magnitudes is possible. However the spectral shapes may be compared and such comparisons are shown in Figs. 4 and 5. The curves are normalized to have the same maximum height. It will be seen that the spectral shapes as determined theoretically and experimentally are in excellent agreement. Similar agreement was found for scattered radiation generated by X-rays with primary half-value layers of 1.7 and 3.1 mm of copper.

In conclusion it may be said that satis-

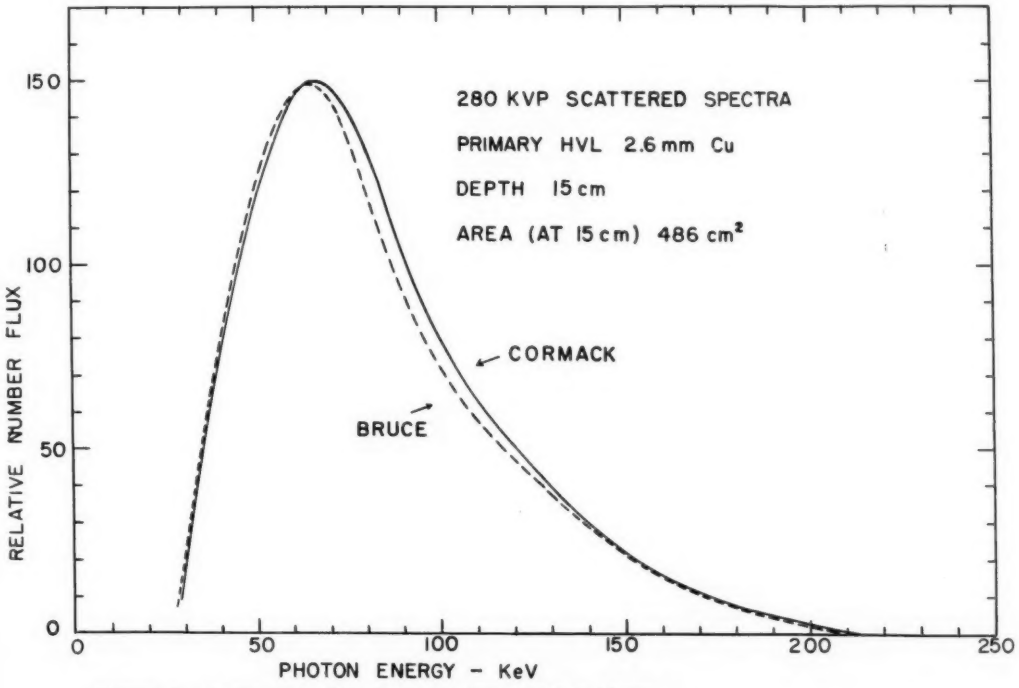

Figure 5 — Same as in Fig. 4 except that depth is 15 cm.

factory agreement was found between scattered spectra calculated from Bruce's tables and spectra measured experimentally. It appears that Bruce's data may be used with confidence in calculating integrated scattered spectra from known primary spectra.

ACKNOWLEDGMENT: This investigation was supported by a grant from the National Cancer Institute of Canada. The assistance of Miss Carole Dier and Miss Edna Rapp is gratefully acknowledged.

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CLINICAL STAGE CLASSIFICATION OF MALIGNANT TUMOURS OF THE BREAST ("T.N.M. System")

The Committee on Clinical Stage Classification and Applied Statistics of the International Union Against Cancer, in July 1959 revised the classification of breast cancer previously presented at the 6th International Cancer Congress in London and recommended that the proposed clinical stage classification for breast be published in leading medical journals throughout the world.

The Editors of the Journal of the Canadian Association of Radiologists have received an abstract of this most recent modification of breast tumour classification, with the request that it be published.

While space does not permit publication in these pages, the attention of our readers is directed to the abstract published in the Canadian Medical Association Journal of February 6, 1960, page 319. This important problem should receive the close attention of Canadian radiologists, particularly those interested in the treatment of cancer.

Dr. A. H. Sellers, Director, Division of Medical Statistics, The Department of Health of Ontario, is the Secretary of the Committee on Clinical Stage Classification. Requests for further information or for copies of the complete booklet containing the revised classification (English or French translation) may be addressed to Dr. Sellers.

BOOK REVIEW

The Mediastinum, Ted F. Leigh, M.D., and H. Stephen Weens, M.D., The Ryerson Press, Toronto, 1959, $12.75, Charles C Thomas, Publisher.

This monograph is an excellent review of mediastinal pathology. It deals not only with lesions arising in the mediastinum proper but also with anomalies close to it and systemic processes, both capable of producing abnormal mediastinal shadows.

The first two chapters review the anatomy of the mediastinum with special emphasis on lymph node location and drainage. The next three chapters are devoted to mediastinal emphysema, mediastinitis and hemomediastinum. All the benign and malignant tumoral masses and congenital malformations are discussed in succeeding chapters. Esophageal lesions and diaphragmatic hernias, bone and cartilage lesions producing tumor-like mediastinal shadows are then discussed. Four chapters on mass lesions originating from the pericardium and midline vascular structures are included because they frequently enter into the differential diagnosis of mediastinal disease. The last two chapters include extramedullary hemopoiesis and miscellaneous lesions namely plasmocytomas, amyloidosis, glomus tumor, pancreatic pseudocyst, echinococcus cyst, myxomas and xanthomas.

Every chapter contains a brief exposé of the histologic pathology and microscopic appearance of a lesion, and its radiological characteristics or manifestations are summarized. Each lesion is exemplified with excellent and numerous radiographic reproductions from the author's own cases or publications in current journals. Each chapter ends with a short list of the most important references.

In this work of only 240 pages, it is surprising to see how the authors condensed all the possible mediastinal lesions so adequately. The text is concise and to the point. Each subject is explained sufficiently to give the reader a good understanding and further enhanced by demonstrative radiographic illustrations. Some weaknesses are inherent in such a compact work in that fine radiographic signs are omitted and the differential diagnosis is incomplete when a given tumor is discussed.

This book will be useful to the physician who wants a quick review of mediastinal pathology or for specific reference, because even the rarest tumors or mediastinal localization of a given process are in the contents. Although it will not replace the detailed standard text-books on the mediastinum it can be highly recommended to all radiologists and to those physicians responsible for accurately diagnosing and treating chest diseases.

H-P.L.

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